1 85

52D10

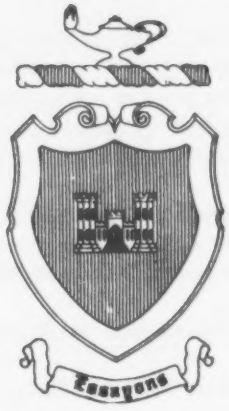
STUDENT WORKBOOK

DIRECT CURRENT MOTORS

NEWARK PUBLIC LIBRARY

JUL 14 1985

U. S. GOVT. PUBS.
DEPOSITORY 376



JANUARY 1981

US ARMY ENGINEER SCHOOL - FORT BELVOIR, VIRGINIA

D 103.120:

This publication supersedes Student Workbook, December 1975, DIRECT CURRENT MOTORS.

Direct Current Motors

INTRODUCTION

Direct current motors and direct current generators have essentially the same components and are very similar in outward appearance. They differ mainly in the way they are used. A D.C. generator converts mechanical energy into electrical energy, while a D.C. motor converts electrical energy into mechanical energy.

The purpose of this lesson is to provide you with an understanding of the construction and operation of direct current motors. After this lesson you will be able to:

1. Explain the principles and construction of the D.C. motor.

2. Explain the construction and operation of the basic D.C. motor.

3. Explain the construction and operation of D.C. motors utilizing an electromagnetic field.

1. D.C. MOTOR PRINCIPLES

The D.C. motor is a mechanical work horse. Many important operations in the military depend directly on a D.C. motor for their power to move. You should therefore become familiar with the theory of motor operation.

a. Motor Action

The operation of a D.C. motor depends on the principle that a current-carrying conductor placed in a magnetic field tends to move as shown in figure 1.

(1) Magnetic field between Poles

A of figure 1 shows the uniform magnetic field which exists between the poles of a magnet when its field coils are connected to a DC source. The lines of force are directed from the north pole to the south pole.

(2) Magnetic field about a Current-Carrying Conductor

B of figure 1 represents a cross section of a current-carrying conductor when the direction of current flow is into the paper (away from the observer). By applying the left hand rule for a current-carrying conductor, it can be found that the direction of the field is counterclockwise, as indicated by the arrows on the lines of force.

(3) Resultant Magnetic Field

Now suppose the conductor in B is placed in the magnetic field of A. When this is done, a resultant field in produced as shown in C of figure 1. Above the conductor, the field is weakened because the field produced by the poles and the field produced by the conductor are opposite in direction and tend to cancel each other. Below the conductor, the two fields are in the same direction and the resultant field is strengthened. Because magnetic lines of force act to push each other apart, those lines below the conductor tend to push the conductor up and those above the conductor tend to push the conductor down. However, the field below is much stronger, having many more lines; so the push upward is greater, with the result that the conductor is moved upward.

(4) Reversing the current Flow

If the current in the conductor is now reversed, the direction of motion of the conductor will also be reversed because, in this case, the field above the conductor is strengthened and the

field below is weakened (See D of figure 1).

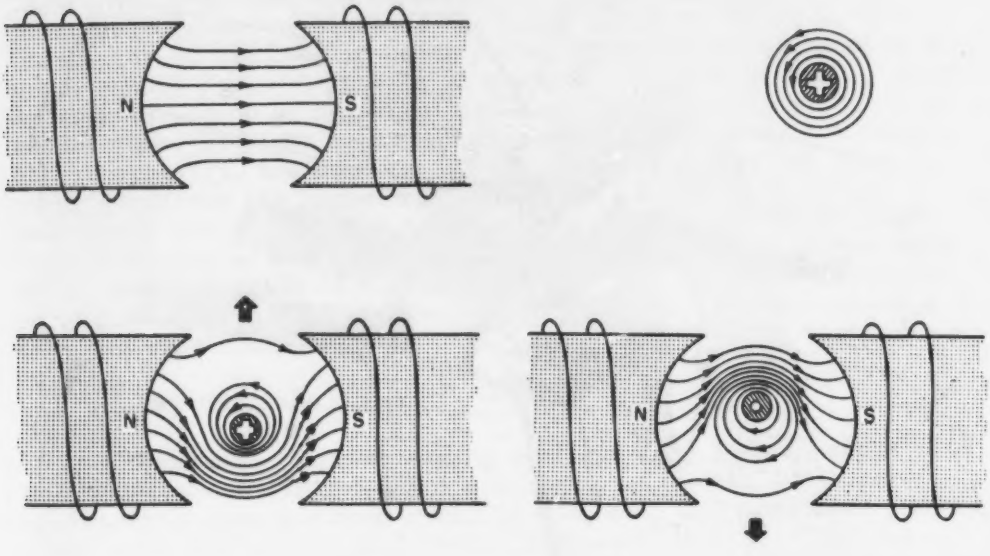


FIGURE 1 - PRINCIPLE OF MOTOR ACTION

b. Right Hand Rule

To find the direction of motion of a conductor, the thumb, first finger, and second finger are extended at right angles to each other, as shown in figure 2. The first finger is pointed in the direction of the lines of force and the second finger is pointed in the direction of the electron flow in the conductor. The thumb then points in the direction of the motion of the conductor.

2. BASIC D.C. MOTOR

The basic DC motor is constructed similarly to the basic DC generator (Figure 3). It consists of a pair of magnetic poles, an armature loop, a commutator, and brushes. When a DC voltage is applied to the brushes, current flows around the loop. The magnetic field produced by the flow of current interacts with the magnetic field produced by the poles of the magnets. The loop rotates under the influence of the resultant magnetic field. The turning force produced by the revolving armature is called "torque."

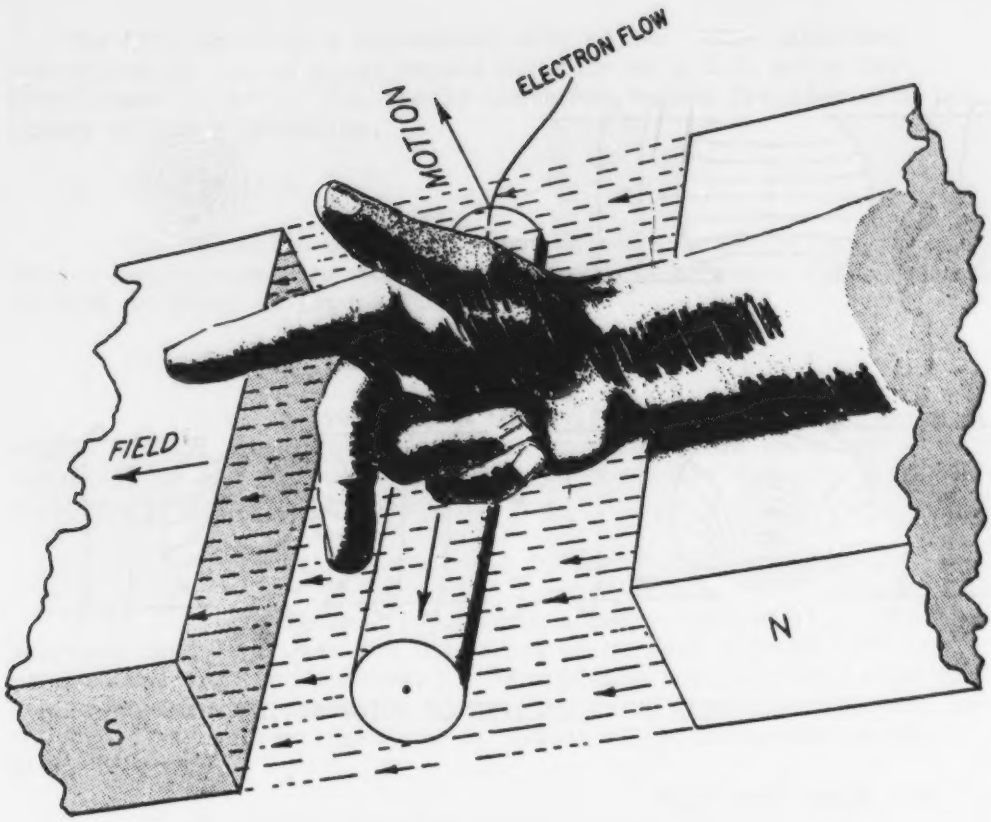


FIGURE 2 - RIGHT HAND RULE

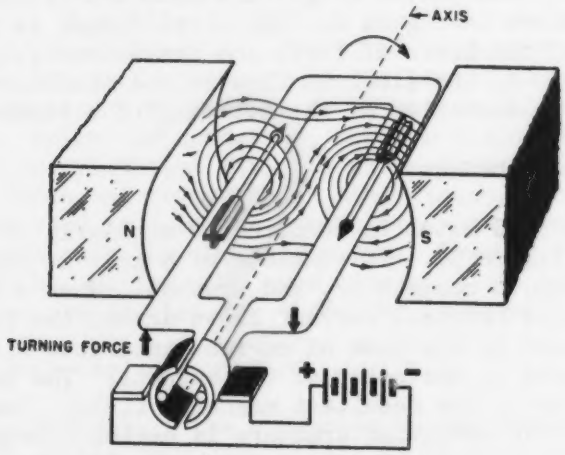


FIGURE 3 - BASIC D.C. MOTOR

READEX FICHE
best copy available

a. Armature Rotation

In order to understand how the armature of a basic DC motor rotates continually, consider the basic DC generator shown in figure 4. Note that the direction of current is indicated by arrows placed alongside the sides of the loop. In A of figure 4, the black side of the loop is being pushed up while the white side is being pushed down - torque is at maximum. In B of figure 4, there is no interaction of magnetic fields so the torque is zero. With zero torque, it might be though that the armature rotation would stop. Normally, the momentum of the armature causes the loop to swing back into the magnetic field again. At the same time, commutator action reverses the direction of current in the loop. In C of figure 4, the black side of the loop is being pushed down while the white side is being pushed up. The torque is again at maximum. This action provides enough force to keep the armature rotating continually.

b. Improving the Torque

The basic DC motor having a single-turn loop is often used to explain the theory of motor operation. However, the torque developed by such a simple motor is too small for practical purposes. Also, each time the loop passes through zero torque, a jerk is introduced in the rotation of the armature. To develop more torque and to eliminate the effect of the zero torque on armature rotation, additional loops are added to the armature. For example, Figure 5 shows an armature with two loops. Note that only the loop in the best position to produce torque is connected to the brushes. Thus, the loop passing through zero torque is never conducting current. By adding more loops to the armature, additional torque is developed and still smoother operation of the armature results. For this reason, practical motors use a large number of loops on the armature and a corresponding large number of segments in the commutator.

c. Counter Electromotive Force

In a DC motor, as the armature rotates, the armature coils cut the magnetic field, inducing a voltage in these coils. By use of the left-hand rule for a generator to determine the direction of this induced voltage, it is found to oppose the applied voltage. It is, therefore, called a counter voltage or counter EMF.

(1) Strength

The strength of the counter EMF depends on the speed of rotation and the strength of the magnetic field. The stronger the field and the faster the rotating speed, the larger will be the counter EMF. However, the counter EMF will always be less than the

applied voltage due to the resistance of the armature coils. Figure 6 represents the counter EMF as a battery opposing the applied voltage, with the total armature resistance shown as a single resistor.

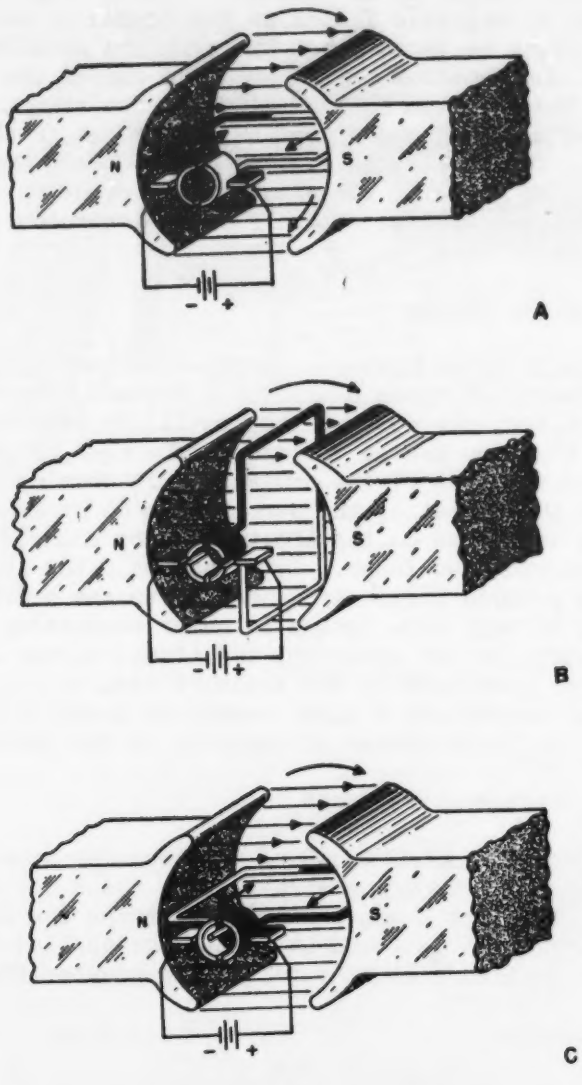


FIGURE 4 - ARMATURE ROTATION

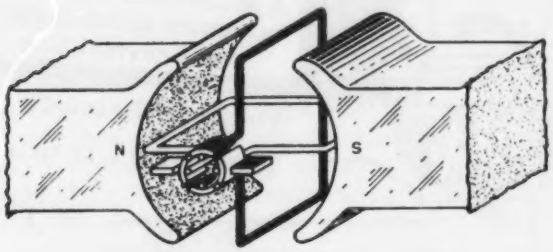


FIGURE 5 - TWO LOOP MOTOR

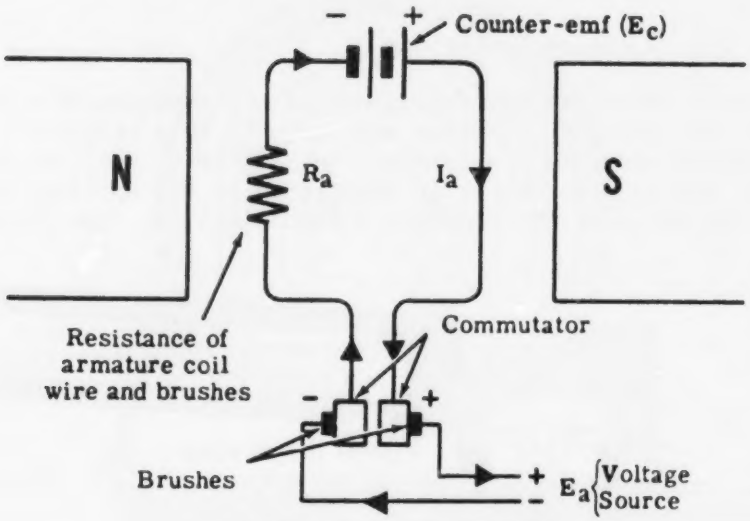


FIGURE 6 - COUNTER EMF

(2) Armature Current

What actually moves the armature current (I_a) through the armature coils is the difference between the voltage applied to the motor (E_a) minus the counter EMF (E_c). Thus $E_a - E_c$ is the actual voltage effective in the armature and it is this effective voltage which determines the value of current flowing through the armature resistance (R_a). The armature current then can be determined by Ohm's Law, $I_a = \frac{E_a - E_c}{R_a}$

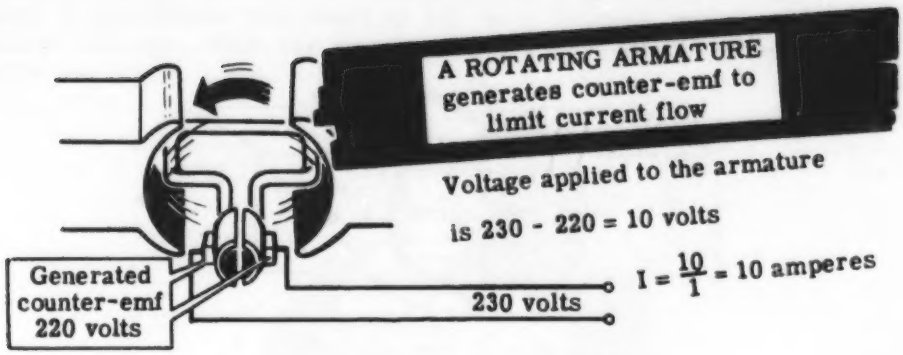


FIGURE 7 - ARMATURE CURRENT

(3) Armature Resistance

The internal resistance of the armature of a DC motor is very low, usually less than one ohm. If this resistance were all that limited the armature current, this current, would be very high. However, the counter EMF is in opposition to the applied voltage and limits the value of the armature current that can flow (Figure 7).

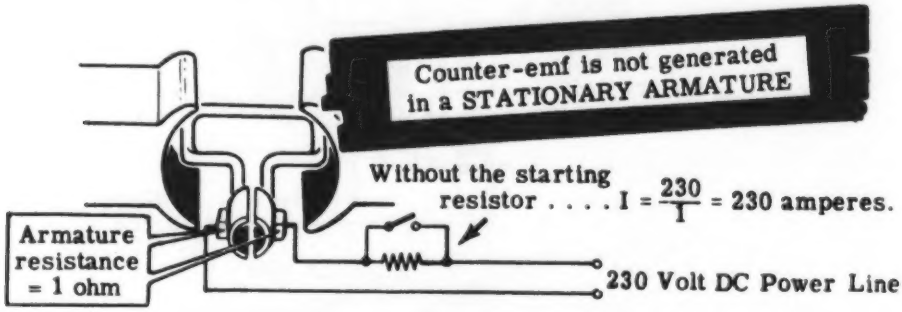

Counter-emf is not generated
in a STATIONARY ARMATURE
Without the starting
resistor . . . . I = 230/1 = 230 amperes.
Armature
resistance
= 1 ohm
230 Volt DC Power Line

FIGURE 8 - STARTING RESISTANCE

(4) Starting Resistance

When the motor is just starting and the counter EMF is too small to limit the current effectively, a temporary resistance called the "starting resistance" must be put in series with the armature (Figure 8). This keeps the current flow within safe limits and prevents the armature from being burned out. As the motor speeds up, the counter EMF increases and the resistance can be gradually reduced, allowing a further increase in speed and counter EMF. At

normal speed, the starting resistance is completely shorted out of the circuit.

3. ELECTROMAGNETIC FIELD

The basic DC motor discussed so far has used permanent-magnet fields. However, since a DC voltage must be applied to the armature doesn't it seem logical to use part of the direct current to set up an electromagnetic field. Most DC motors use field coils instead of permanent magnets. Direct current motors using field coils are classified according to their field connections into three groups: shunt, series, and compound types.

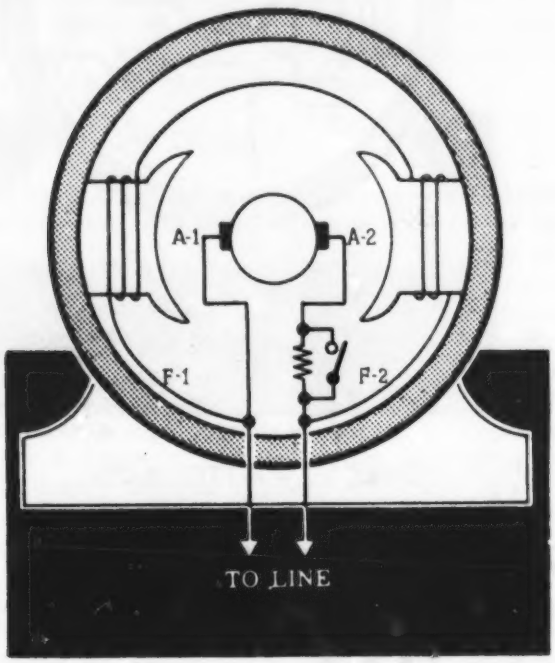


FIGURE 9 - SHUNT MOTOR

a. Shunt Motor

In a shunt connected motor, the field coils are connected directly across the line (Figure 9). The strength of the electromagnetic field is independent of variations in mechanical load and armature current.

(1) Constant Speed

In a shunt motor, the variation of speed from no-load to full load is only about 10 percent of the no-load speed. For this reason, shunt motors are considered constant speed motors.

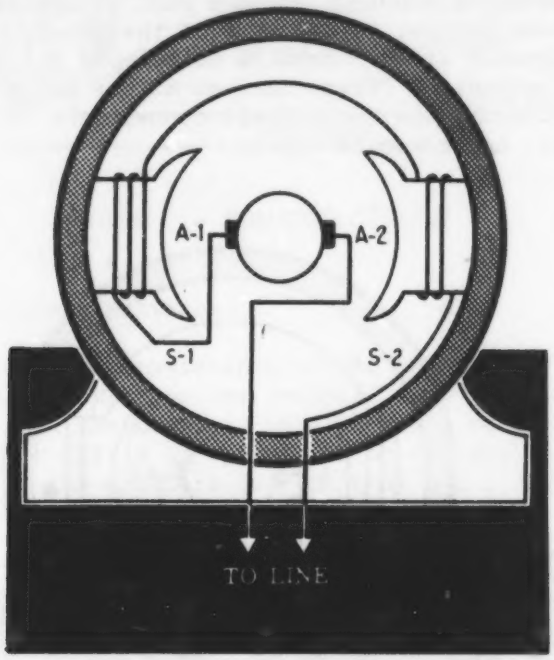


FIGURE 10 - SERIES MOTOR

(2) Low starting Torque

When a shunt motor is started, a starting resistance must be connected in series with the armature to limit the armature current. Since the starting current is small, due to this added resistance, the starting torque will be low. Shunt motors are used where constant speed under varying load is desired and where it is possible for the motor to start under light or no load conditions.

b. Series Motor

The series motor has its field connected in series with the armature and the load, as shown in Figure 10. The field coil consists of a few turns of heavy wire, since the entire armature current flows through it. If the load increases, the motor slows

down and the counter-EMF decreases, which allows the current to increase and supply the heavier torque needed. The series motor runs very slowly with heavy loads and very rapidly with light loads. If the load is completely removed, the motor will speed dangerously and fly apart, since the current required is very small and the field very weak, so that the motor cannot turn fast enough to generate the amount of counter-EMF needed to restore the balance. Series motors must never be run under no-load conditions, and they are seldom used with belt drives where the load can be removed.

(1) Variable Speed

You can see that series motors are variable speed motors - that is, their speed changes a great deal when the load is changed. For this reason series motors are seldom used where a constant operating speed is needed, and are never used where the load is intermittent - where the load changes frequently or is put on and taken off while the motor is running.

(2) High Starting Torque

The torque - the turning force - developed by any DC motor depends on the armature current and the field strength. In the series motor, the field strength itself depends on the armature current, so that the amount of torque developed depends doubly on the amount of armature current flowing. When the motor speed is low, the counter-EMF is, of course, low and the armature current is high. This means the torque will be very high when the motor speed is low or zero, such as when the motor is starting. The series motor is said to have a high starting torque. There are special jobs which require a heavy starting torque and the high rate of acceleration this heavy torque allows.

c. Compound Motor

A compound motor is a combination series and shunt motor (Figure 11). The field consists of two separate sets of coils. One set, whose coils are wound with many turns of fine wire, is connected across the armature as a shunt field. The other set, whose coils are wound with few turns of heavy wire, is connected in series with the armature as a series field.

4. DC MOTOR CONTROLS

Simple switches and variable resistors can be used for controlling the action of a DC motor.

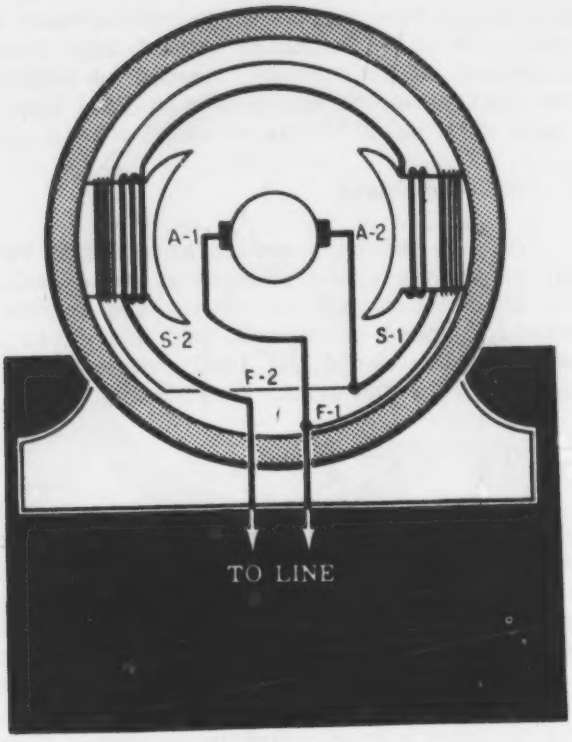


FIGURE 11 - COMPOUND MOTOR

a. Starter

An elementary starter consists of a resistance with taps on it, (Figure 12). This resistance can be progressively shorted out by a knife switch whose contacts connect to the taps on the resistor. When the motor is first started, the switch contacts the end of the resistor so that all of the resistance is in series with the armature. As the motor comes up to speed, the blade is slowly closed. This shorts out more and more of the resistance until, when the switch is completely closed, all of the resistance is shorted out.

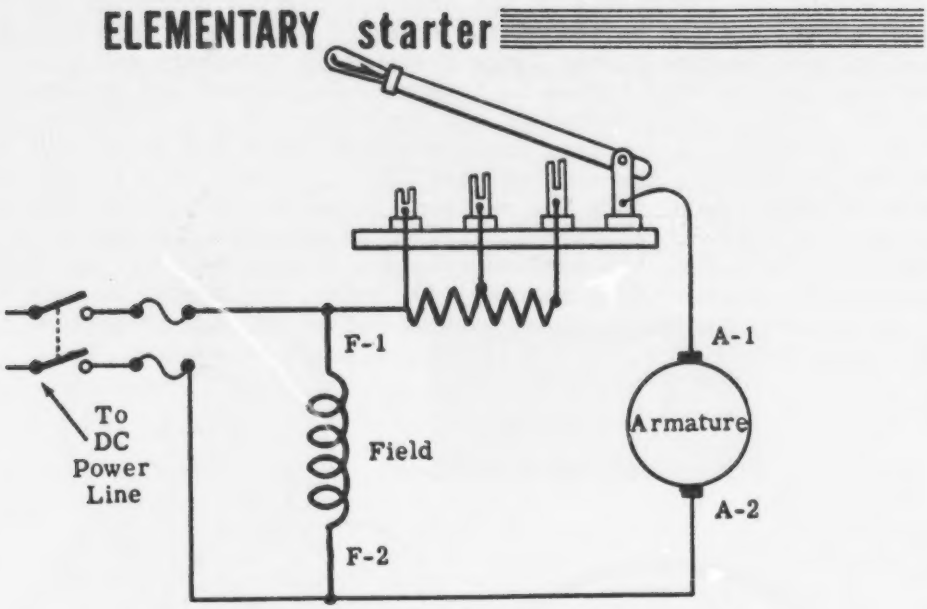


FIGURE 12 - D.C. MOTOR STARTER

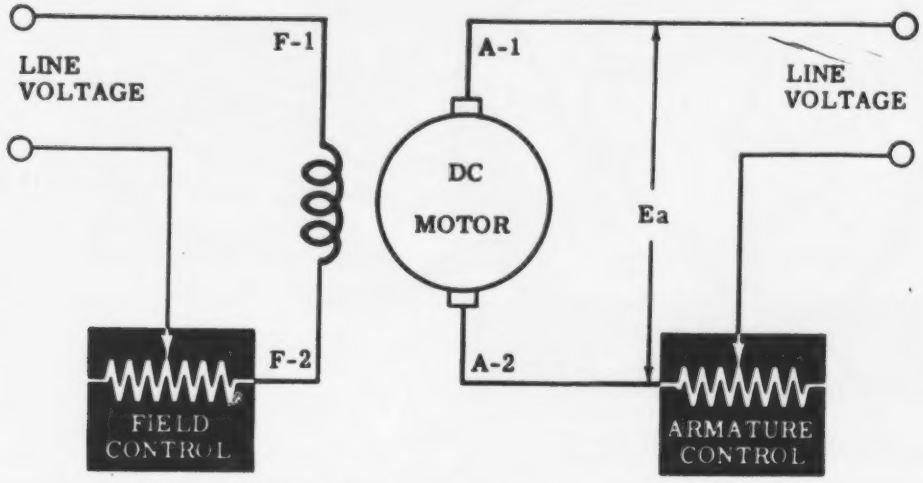


FIGURE 13 - METHODS OF SPEED CONTROL

b. Speed Controller

The motor speed can be varied by controlling the field strength with a field rheostat, or by controlling the voltage

applied to the armature with an armature rheostat (Figure 13). Increasing the resistance in the armature circuit decreases the applied voltage and decreases the speed of rotation. This method is seldom used because a very large rheostat is necessary and also because the starting torque is lowered. Increasing the resistance in the field circuit decreases the field current and therefore the field strength. A decrease field strength means the motor must turn faster to maintain the same counter EMF. In fact, if a field circuit should become open, only the residual magnetism is left and the motor speed will increase dangerously trying to maintain the counter EMF necessary to oppose the applied voltage. Always be sure the field circuit is closed before running a DC motor, and always be sure the starting resistance is set to maximum before voltage is applied to the armature.

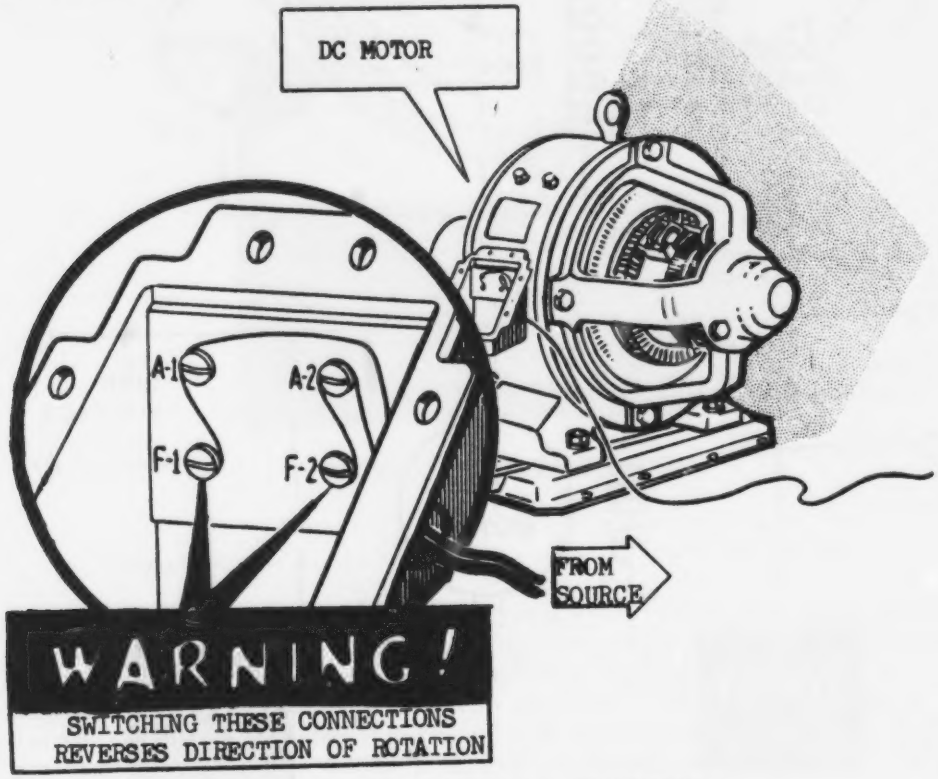


FIGURE 14 - MOTOR TERMINALS

c. Direction of Rotation

The direction of rotation of a DC motor can be changed by changing the connections to the field or the armature at the input

terminal board (Figure 14). The direction of rotation depends upon the direction of the field and the direction of current flow in the armature. If either the direction of the field or the direction of current flow through the armature is reversed, the rotation of the motor will reverse (Figure 15). However, if both are reversed at the same time, the motor will continue rotating in the same direction. Ordinarily a motor is set up to do a particular job which requires a fixed direction of rotation. However, there are times when you may find it necessary to change the direction of rotation. Remember that you must reverse the connections of either the armature or the field, but not both.

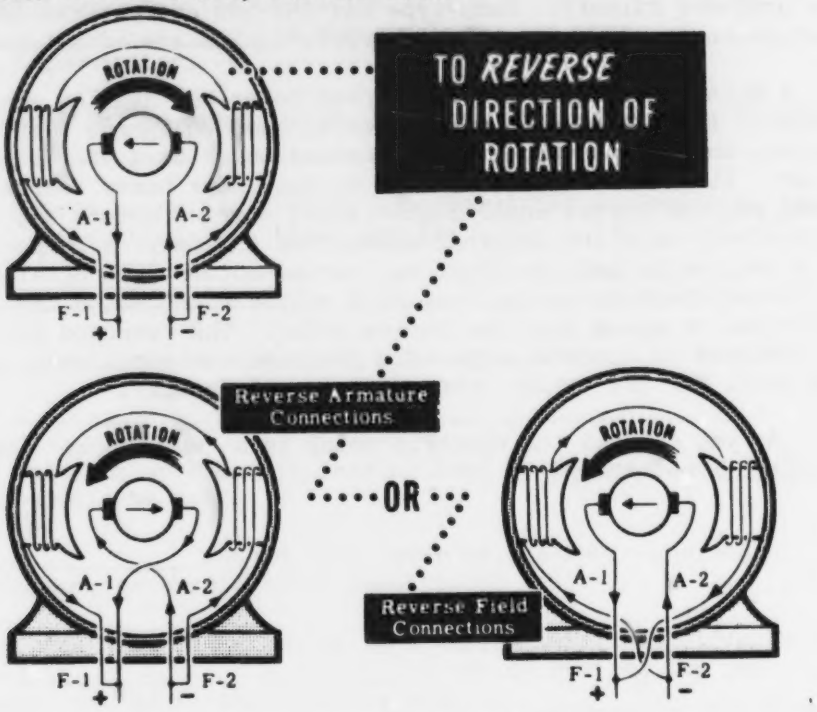


FIGURE 15 - DIRECTION OF ROTATION

SUMMARY

The construction of a DC motor is essentially the same as that of a DC generator. The DC generator converts mechanical energy into electrical energy, while the DC motor converts electrical energy back into mechanical energy. A DC generator may be made to function as a motor by applying a suitable source of direct voltage across the normal output electrical terminals.

The operation of a DC motor depends on the principle that a current-carrying conductor placed in a magnetic field tends to move. A convenient method of determining the direction of motion is by use of the right-hand motor rule.

There are various types of DC motors, depending on the way the field coils are connected. Shunt motors have the field coils connected in parallel with the armature circuit. Series motors have the field coils connected in parallel with the armature circuit. Compound motors have two sets of coils. One set is connected in parallel with the armature circuit, and another set in series with the armature circuit. Each type has its own characteristics and is used in equipment where these characteristics are advantageous.

A shunt motor is a constant speed motor but has low starting torque. It is used with many types of shop equipment such as drills, lathes, and milling machines. A series motor is a variable speed motor. It has low speed and high torque under heavy load, and high speed and low torque under light loads. Series motors are used extensively to start internal combustion engines. A compound motor is a compromise between shunt and series motors. It develops an increased starting torque over that of the shunt motor and has less variation in speed than the series motor. The compound motor may be designed to operate a specific piece of equipment where neither the shunt nor the series motor proved satisfactory.

As you can see the electric motor is a "work horse" for modern electrical machinery.

STUDY QUESTIONS

1. A D.C. Motor converts _____ energy into _____ energy.

2. A current carrying conductor placed in a magnetic field tends to _____.

3. The action that turns the armature is called _____.

4. We can smooth out the operation of a D.C. Motor by adding more _____ to the armature, and more _____ to the commutator.

5. The force in the armature that opposes applied voltage is called _____ _____.

6. D.C. Motors using field coils are classified according to their field connections into three groups:

   a. _____

   b. _____

   c. _____

7. When constant speed under varying load is desired a DC _____ motor should be used.

8. _____ motors must never be run under no-load conditions, or varying load conditions.

9. Motor speed can be varied by controlling the field strength with a _____ _____, or by controlling the voltage applied to the armature with an _____ _____.

10. The direction of rotation depends upon the direction of the field, and the direction of current flow in the _____.

STUDENT NOTES

1. INTRODUCTION

DEVELOPMENT

1. D.C. MOTOR PRINCIPLES

2. BASIC D.C. MOTOR

3. ELECTROMAGNETIC FIELD

SUMMARY

☆U.S. Government Printing Office: 1986—491-036/52444